Mercury's Dynamic Magnetosphere

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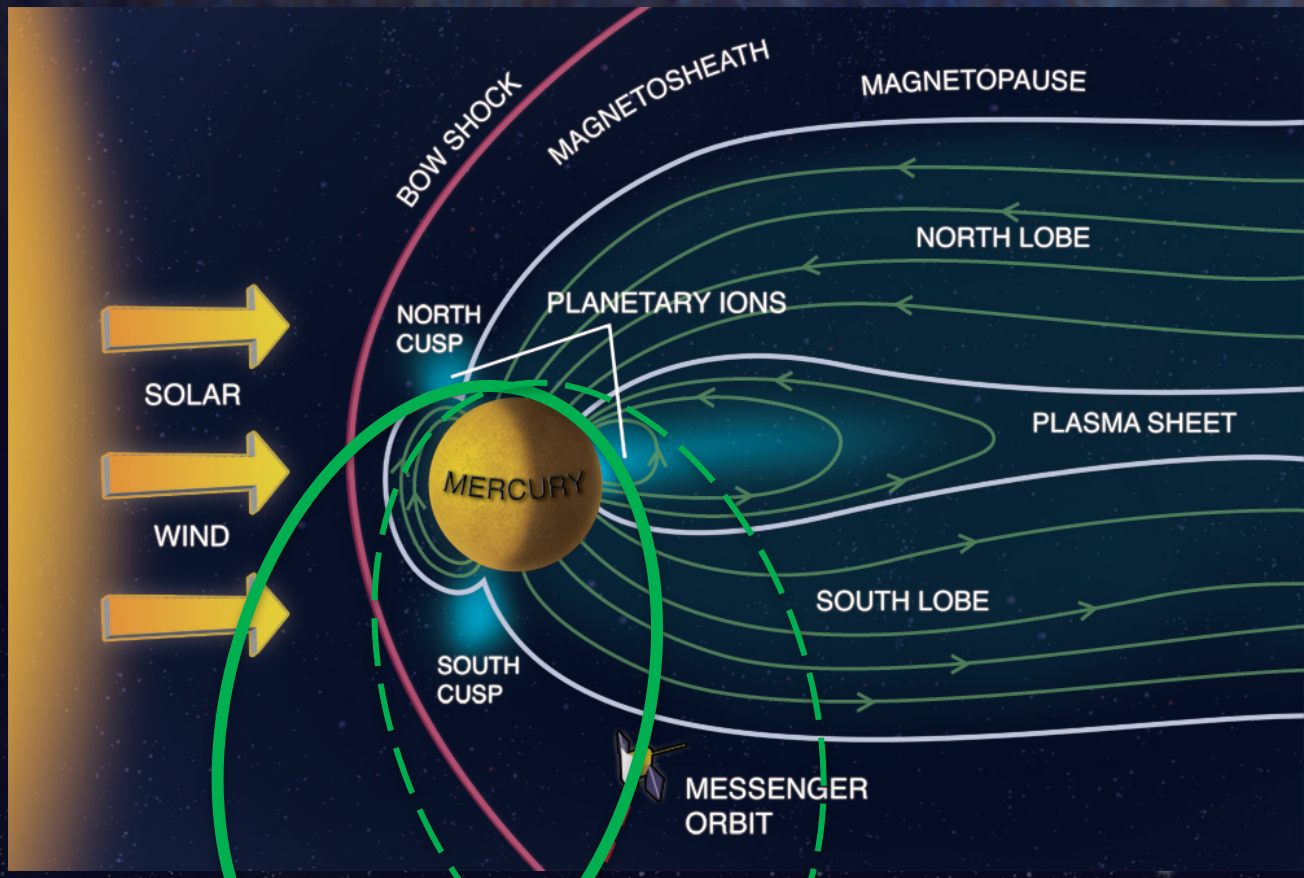
Heliophysics Seminar
Princeton University
6 October 2018

COLLEGE OF ENGINEERING
CLIMATE & SPACE
UNIVERSITY OF MICHIGAN

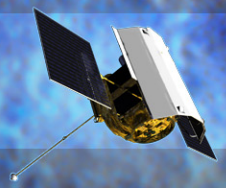
MESSENGER
MErcury Surface, Space ENvironment, GEochemistry, and Ranging

1. Mercury's Magnetic Field & Magnetosphere

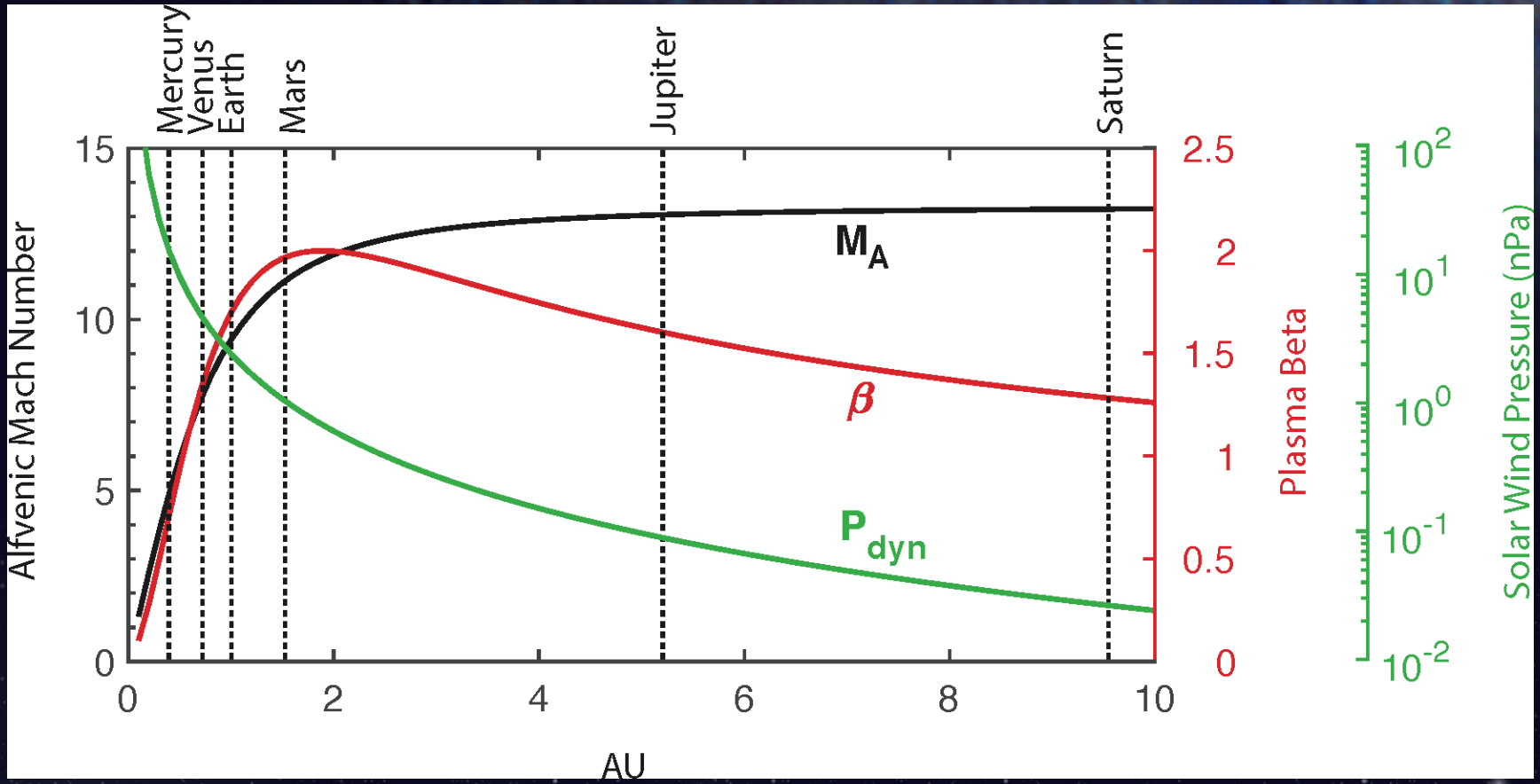
- Orbit insertion: 18 March 2011.
- Elliptical, near-polar orbit.
- Inclination: 82.5°.
- Periapsis alt.: 200 km.
- Apoapsis alt.: 15,300 km.
- Orbit period: 12 hr
- Orbit local-time precession: 0.2 h/day.



Zurbuchen et al. (2011)

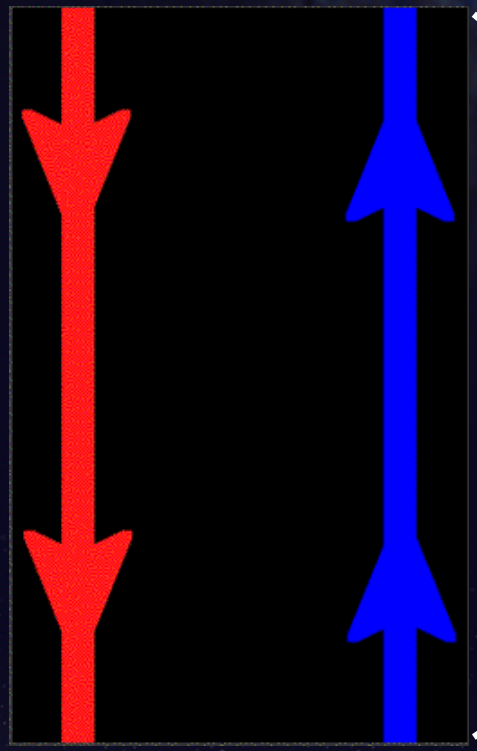


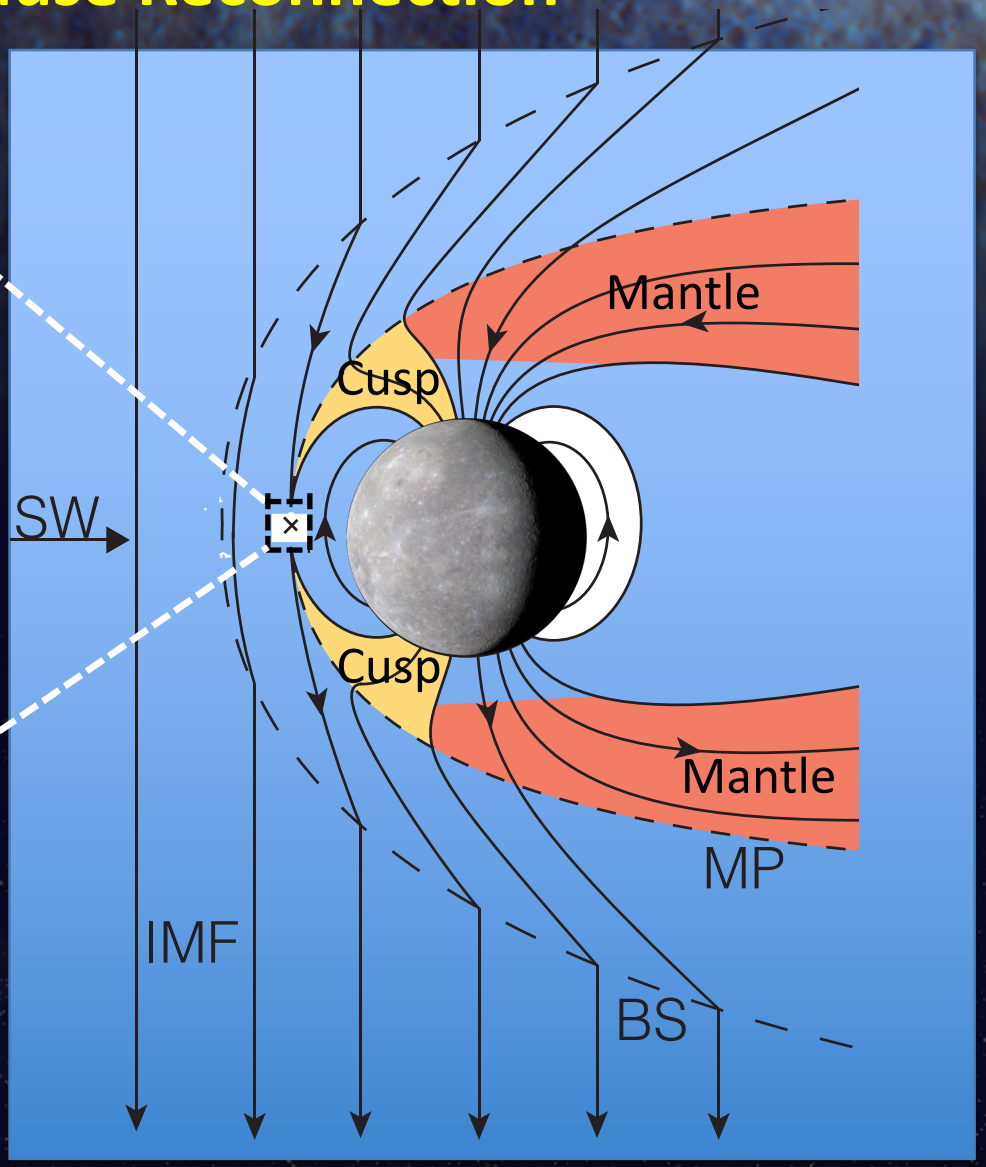
2. Radial Variation in the Solar Wind



Slavin and Holzer (1981)

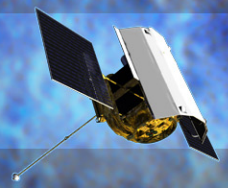
3. Magnetopause Reconnection



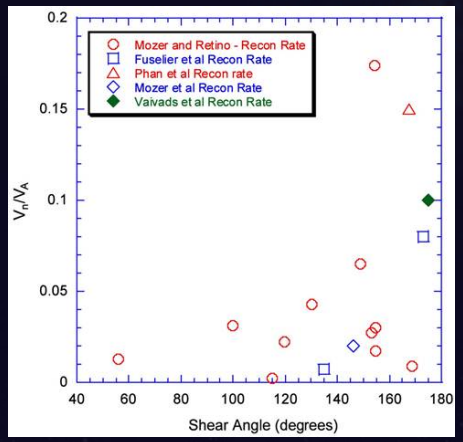


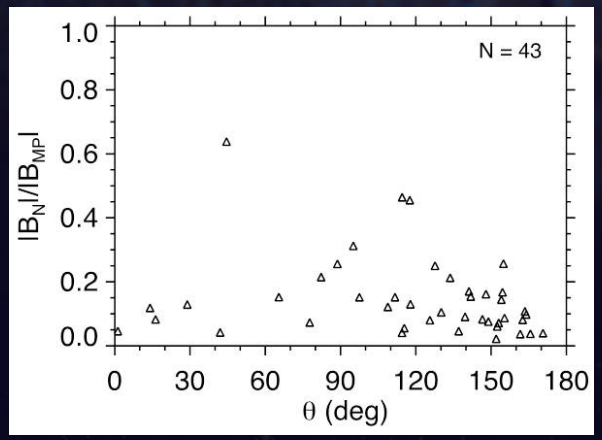
Reconnection and solar wind plasma entry in Mercury's Magnetosphere

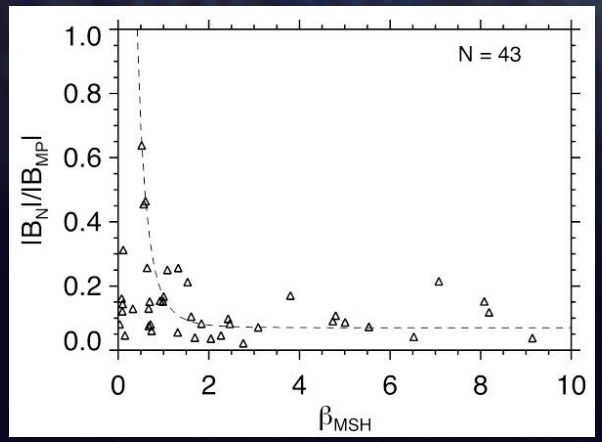
Courtesy J. Jasinski (Univ. Michigan)



Does Reconnection work differently at Mercury?

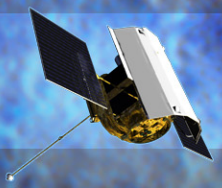






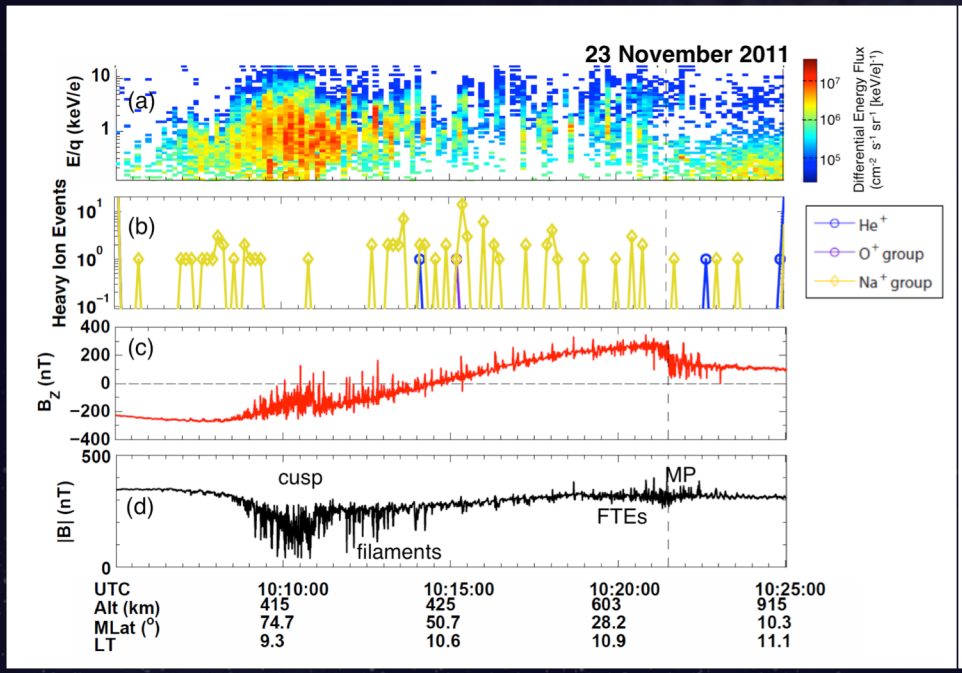
Earth: Strong dependence on interplanetary magnetic field direction. [Mozer et al., 2011]

Mercury: Reconnection is most intense when the interplanetary magnetic field is strong, but there is little or no dependence upon its direction [DiBraccio et al., 2013].

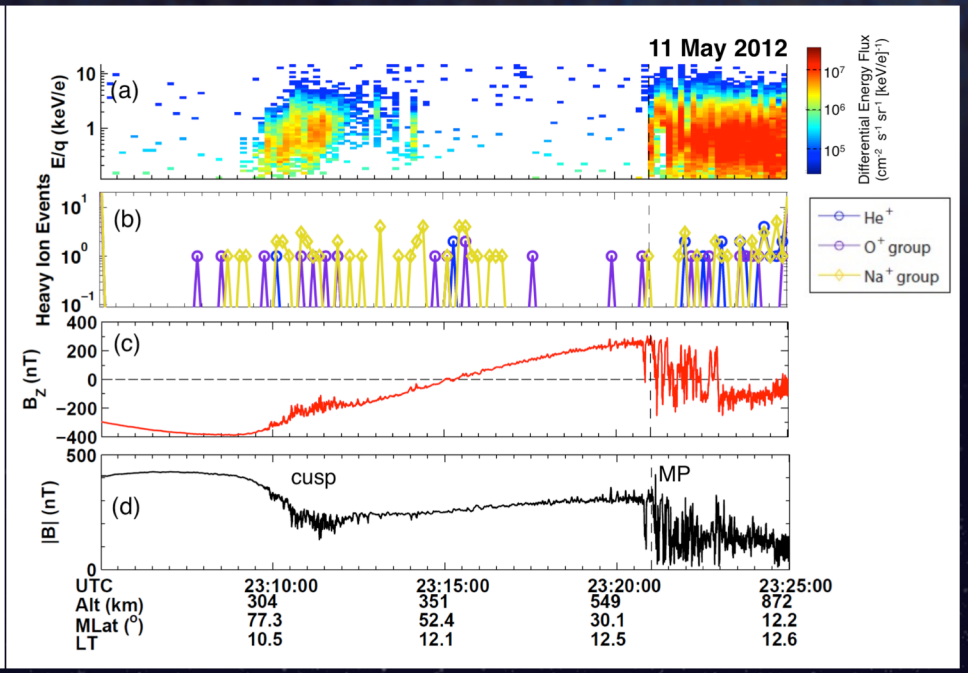


Magnetopause Reconnection Mercury is "Symmetric"

Coronal Mass Ejection



High Speed Stream

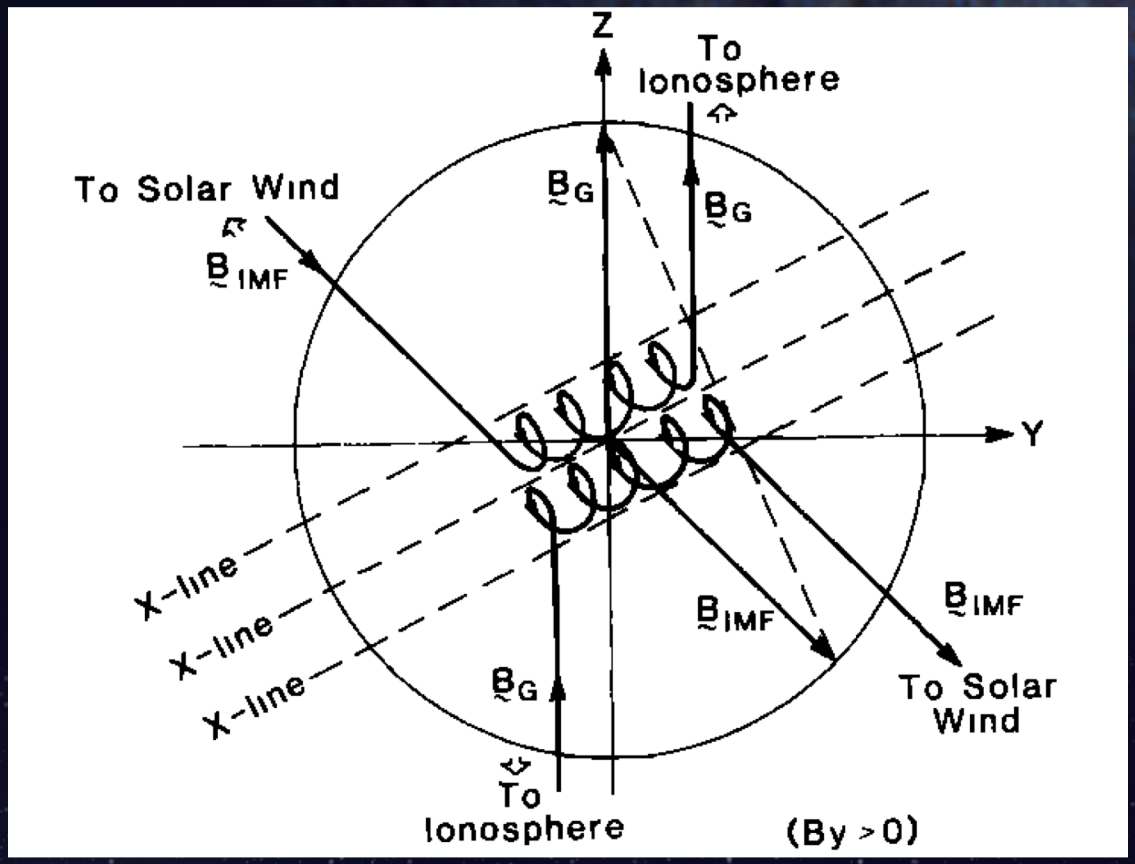


Symmetric Reconnection

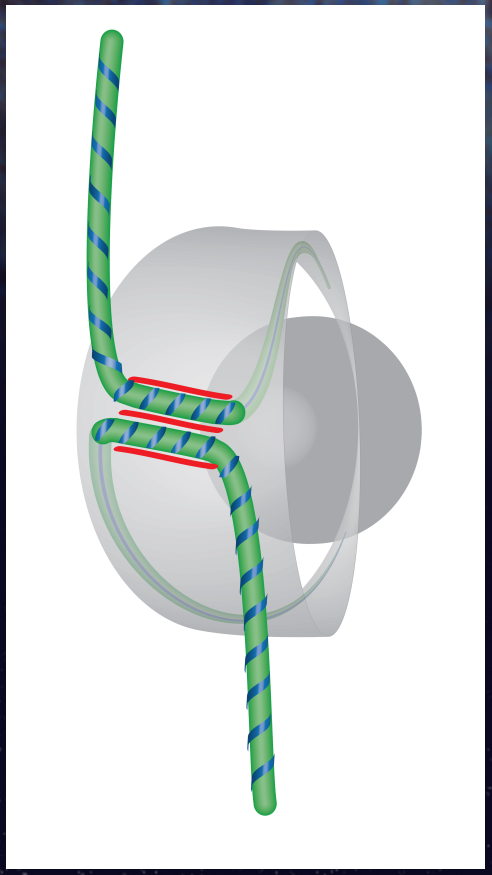
Asymmetric Reconnection

DiBraccio et al. (2013) Slavin et al. (2014)

4. What are Flux Transfer Events (FTEs)?

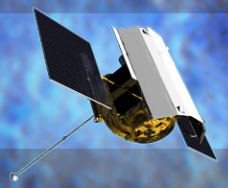


Lee and Fu (1985)

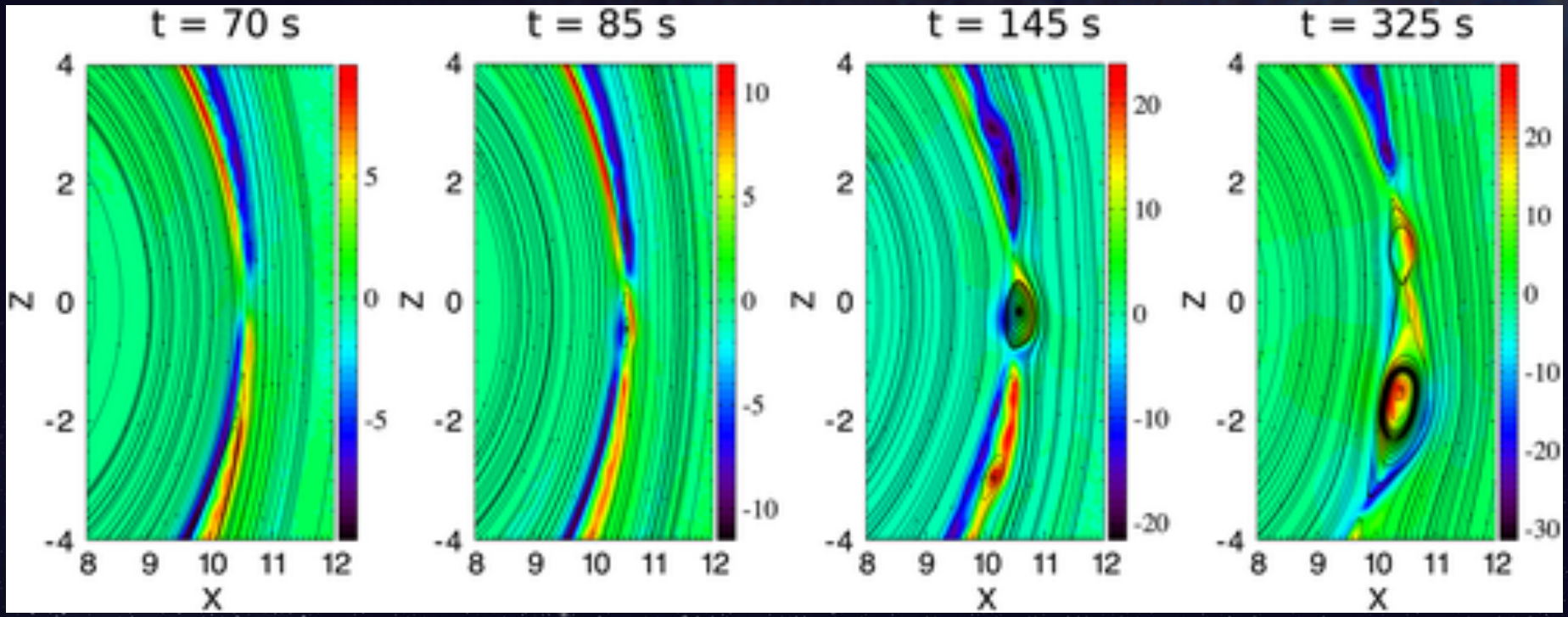


Imber et al. (2015)

Answer: Open magnetic flux ropes formed by multiple x-line reconnection in the magnetopause current layer

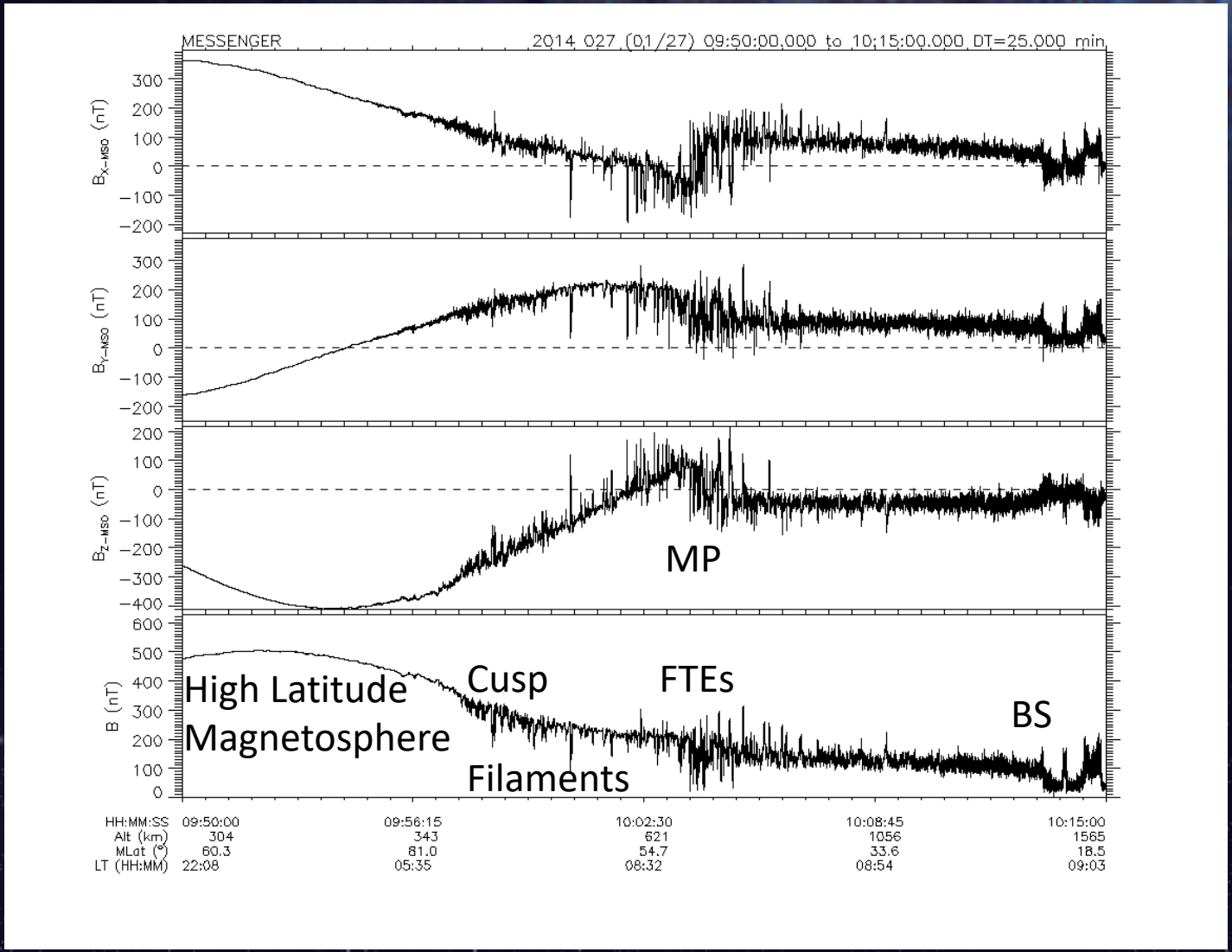


EPIC Global MHD Embedded PIC Simulation of FTE Formation and Evolution



Chen et al. (2017)

FTEs and Cusp Filaments are Common at Mercury!



(see Slavin et al., 2012)

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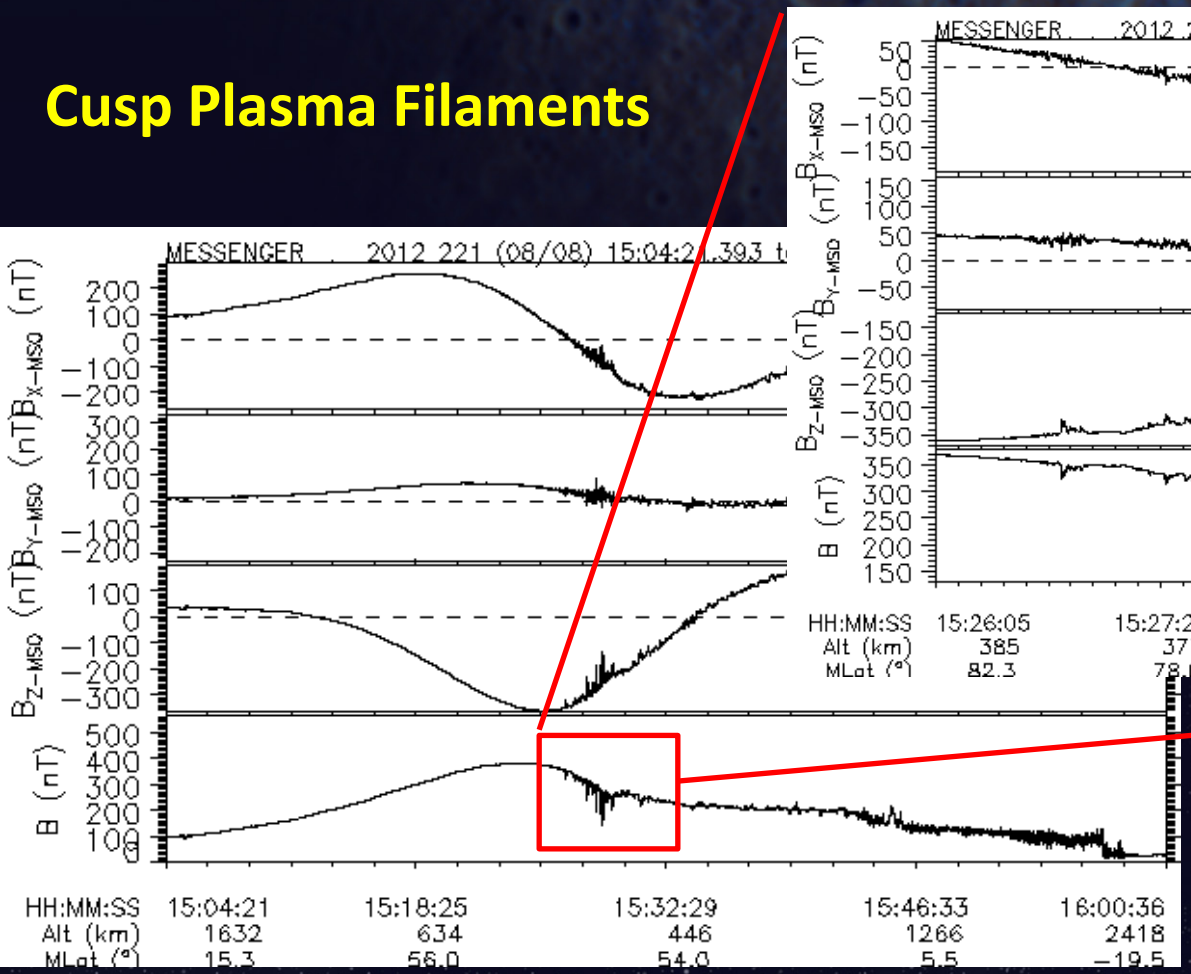
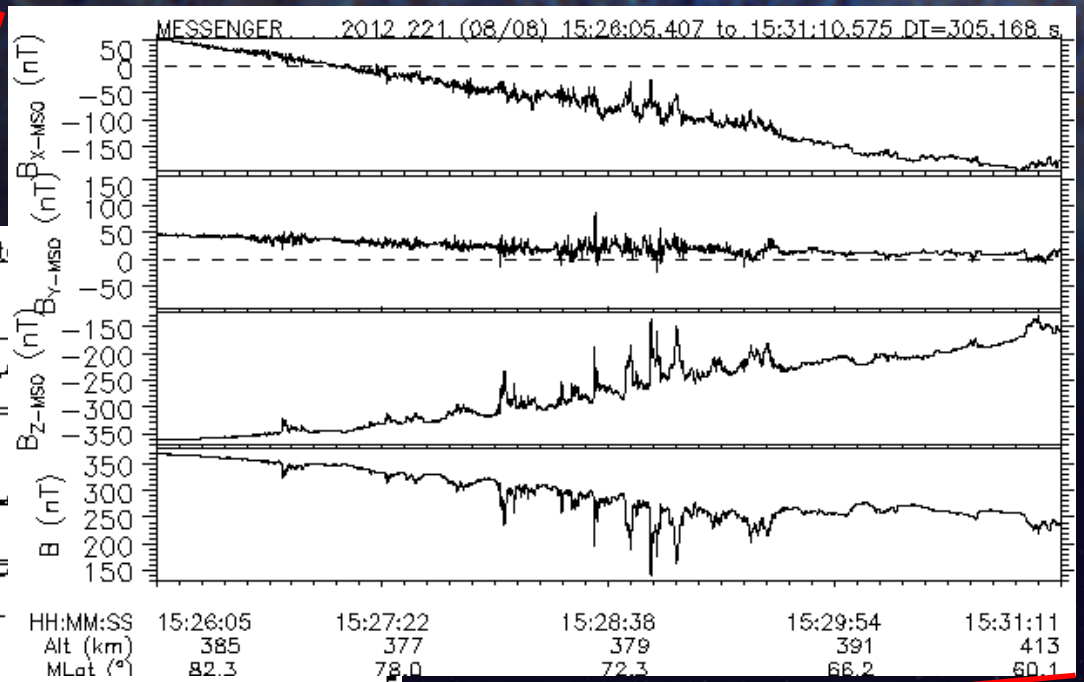
5. Cusp Charged Particle Precipitation

Cusp Plasma Filaments





Poh et al. (2016)

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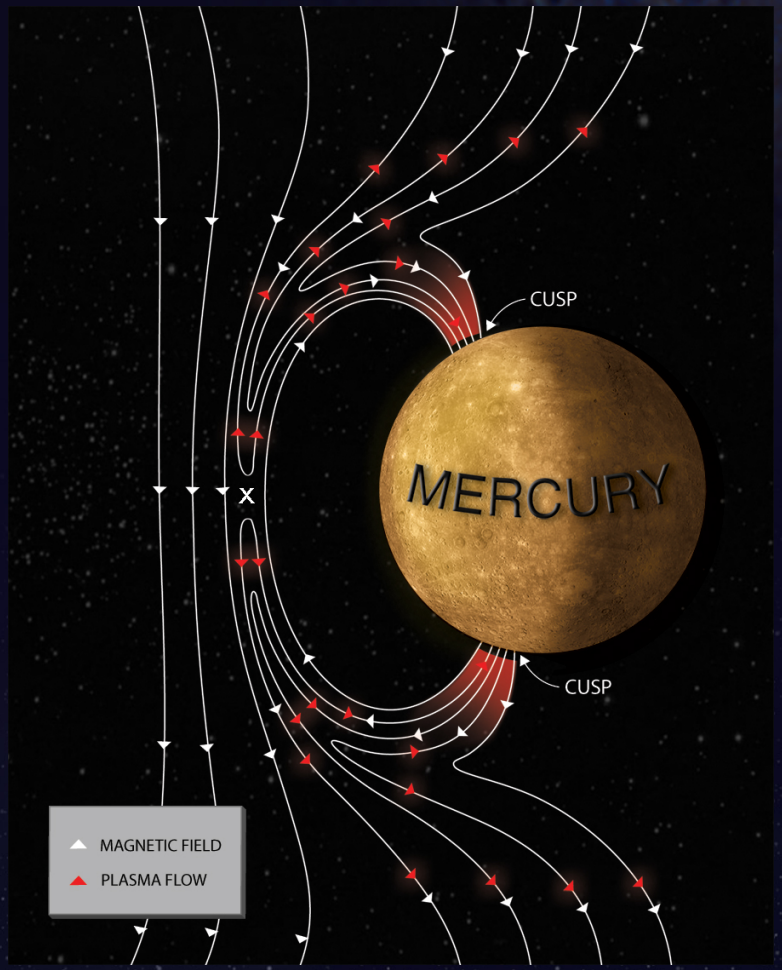
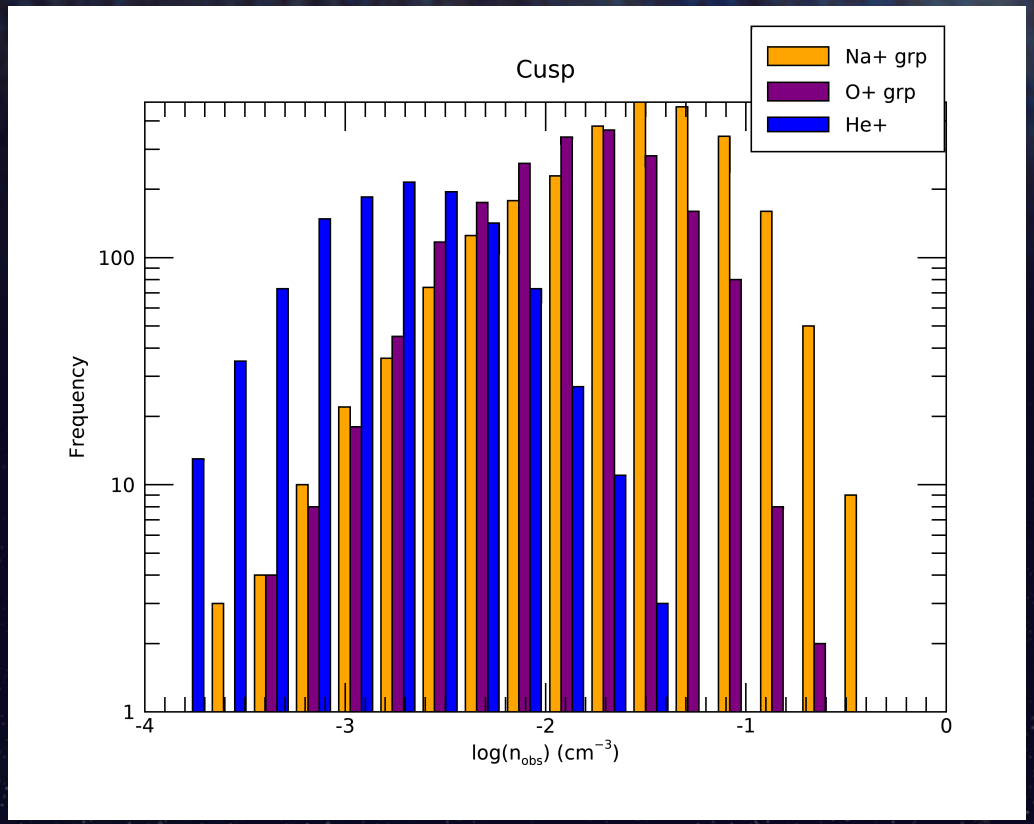
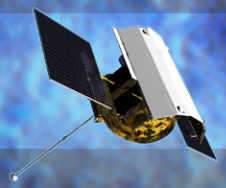
6. Cusp Planetary Ion Outflow



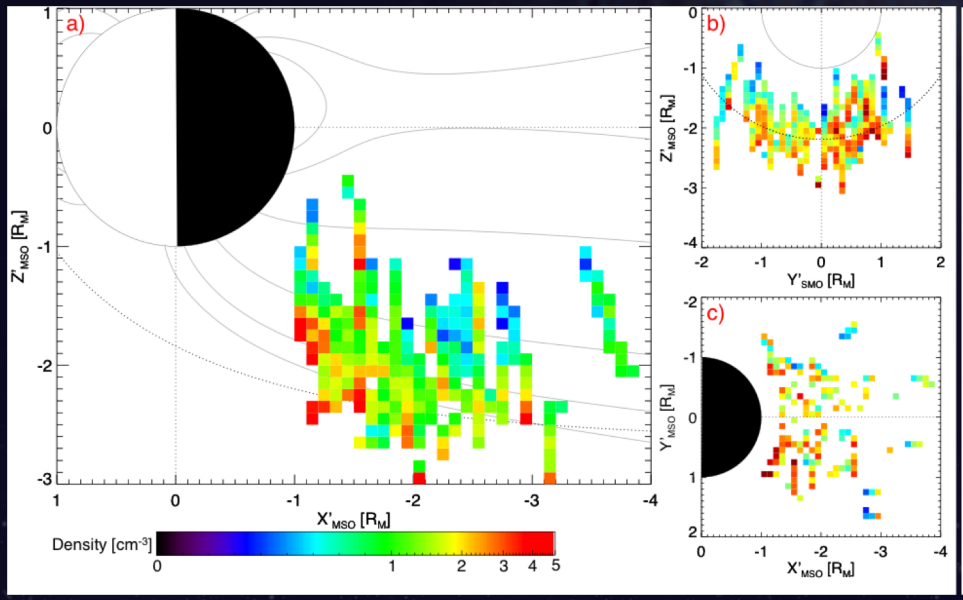
Raines et al. (2014)

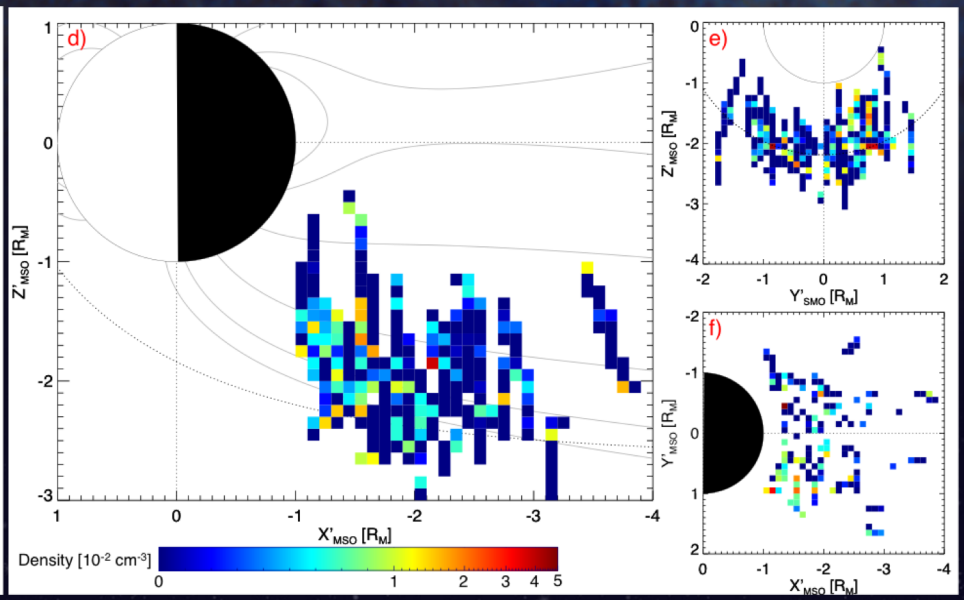


Raines et al. (*in prep*. 2018)



Mercury's H^+ and Na^+ Plasma Mantles



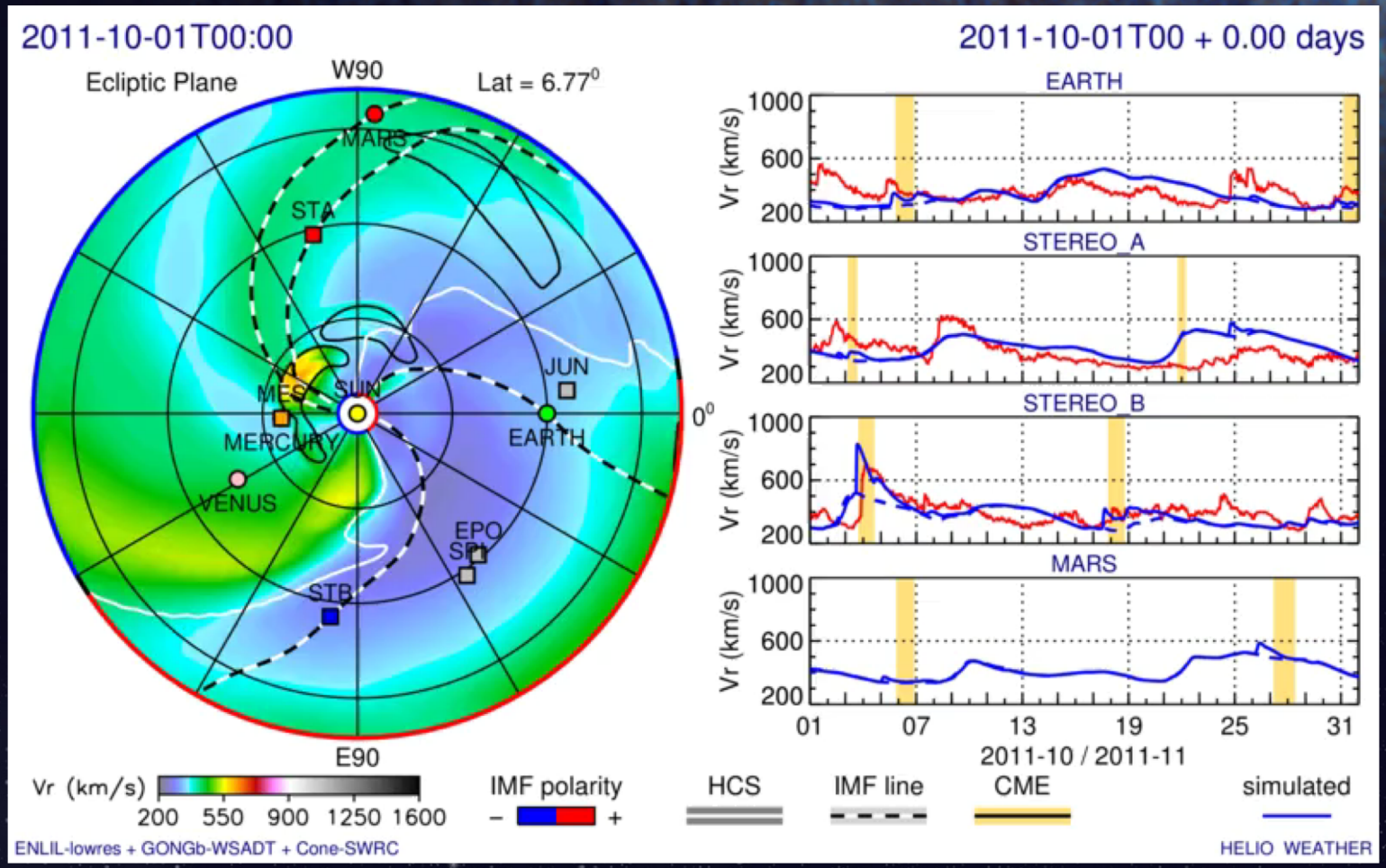


H^+ Ions

Na^+ Ions

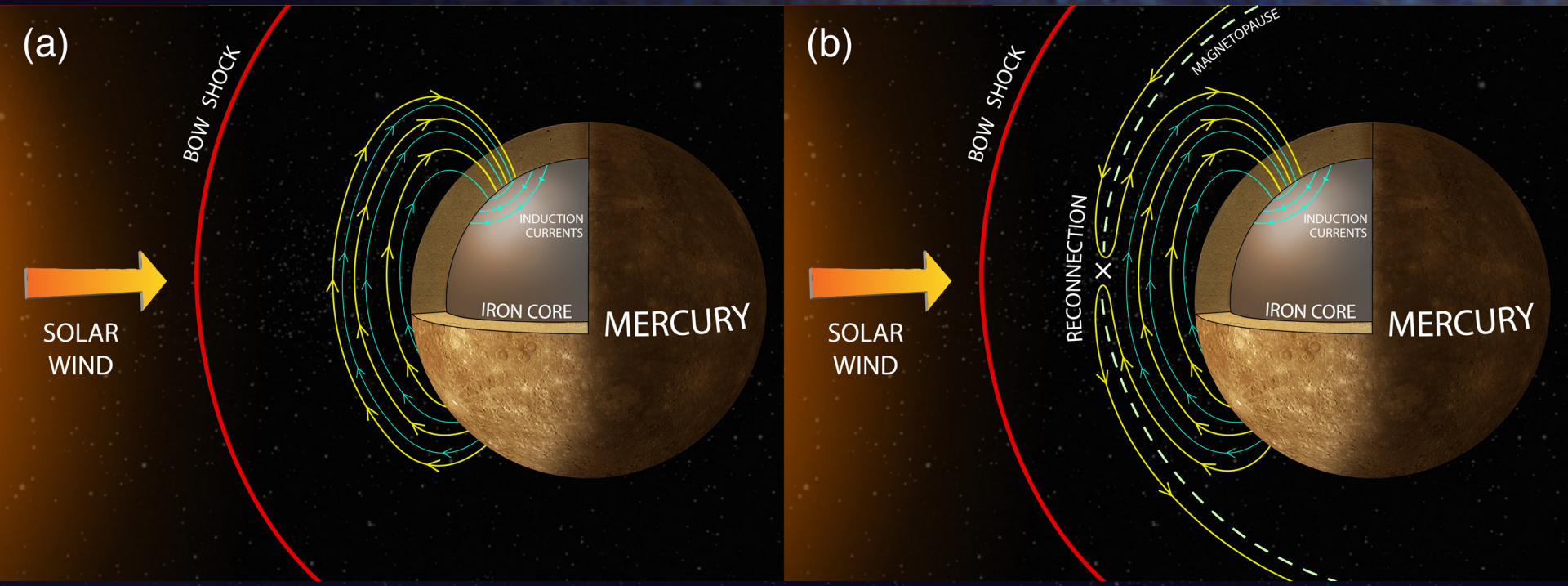
Jasinski et al. (2017)

7. Coronal Mass Ejection Impact on Mercury



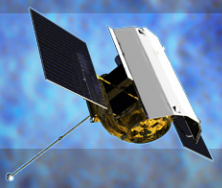
Courtesy CCMC (GSFC)

8. Solar Wind – Core Coupling



"The harder the Solar Wind pushes … the more induction currents add to Mercury's magnetic moment!"

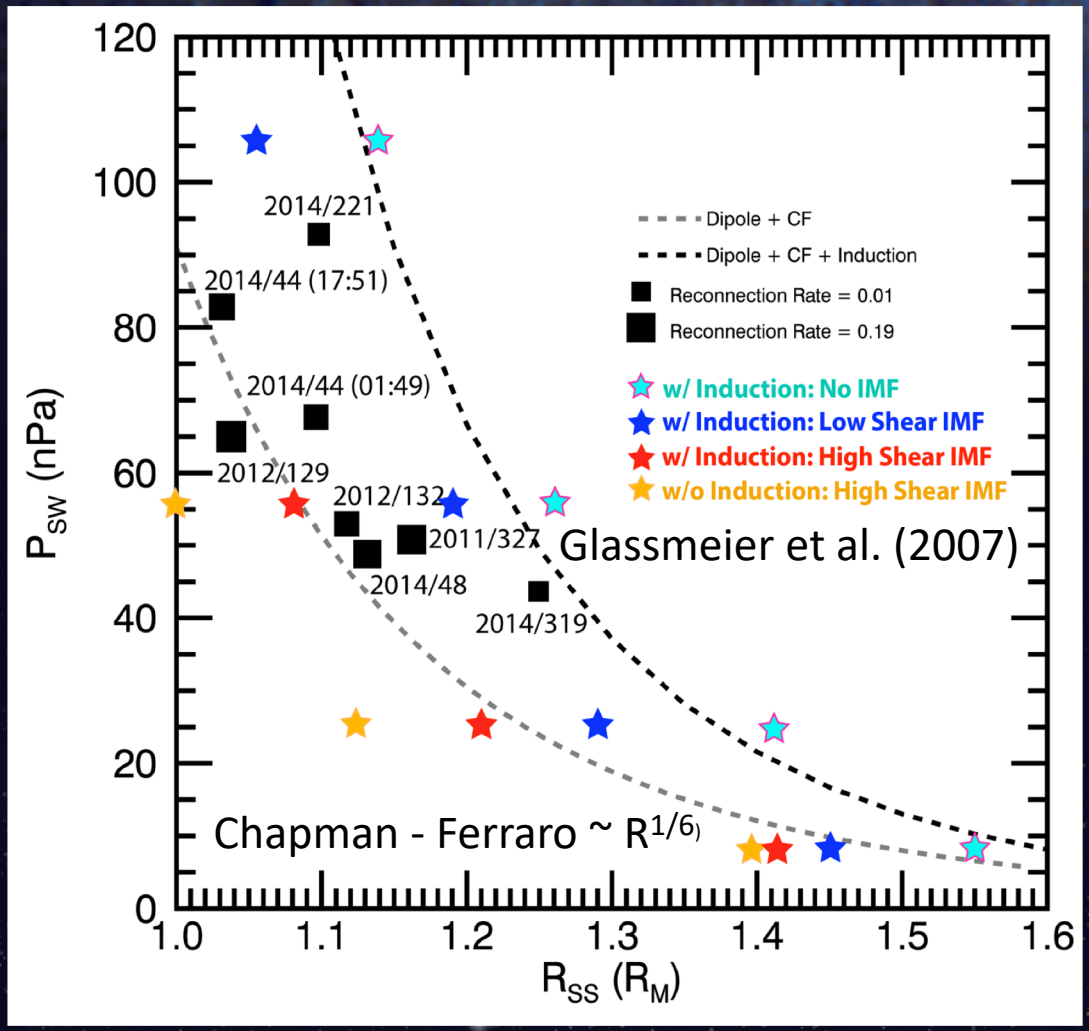
(Slavin et al., 2014)



Dependence of Magnetopause Standoff Distance on P_{dyn}

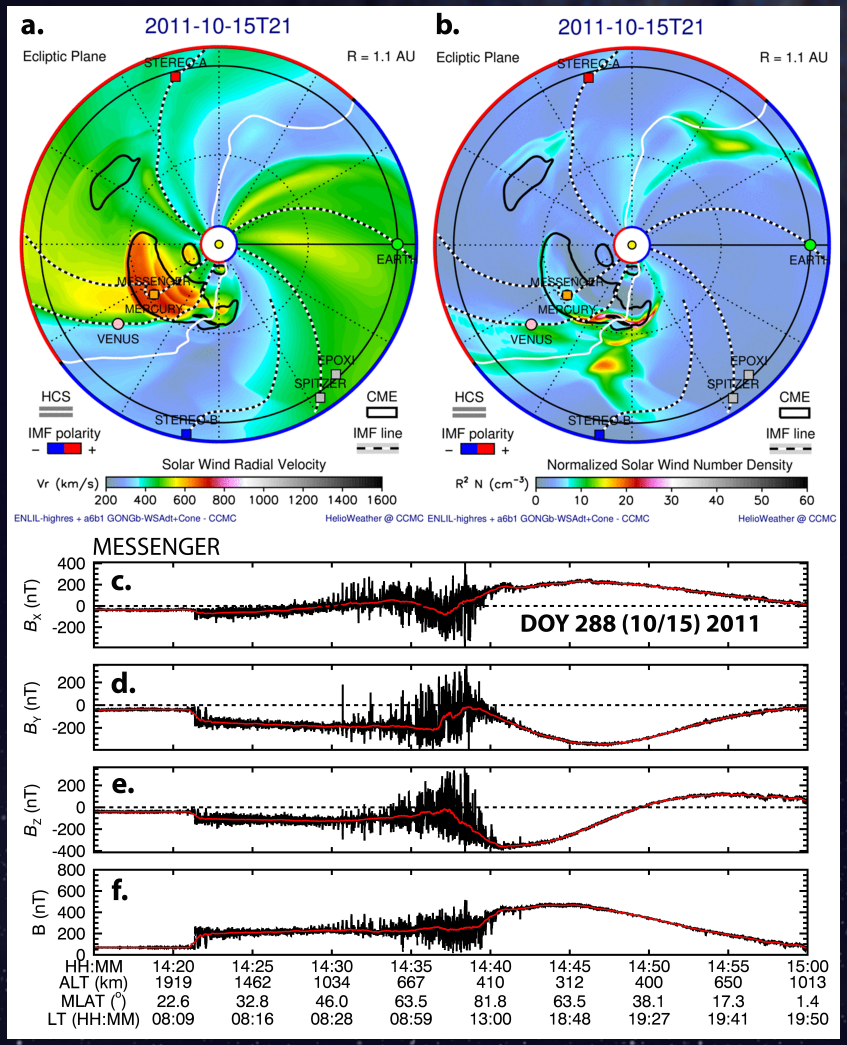
- **MESSENGER Observations of Extreme Events: CMEs & HSS's**
- **Global Simulations with Coupled Interior**

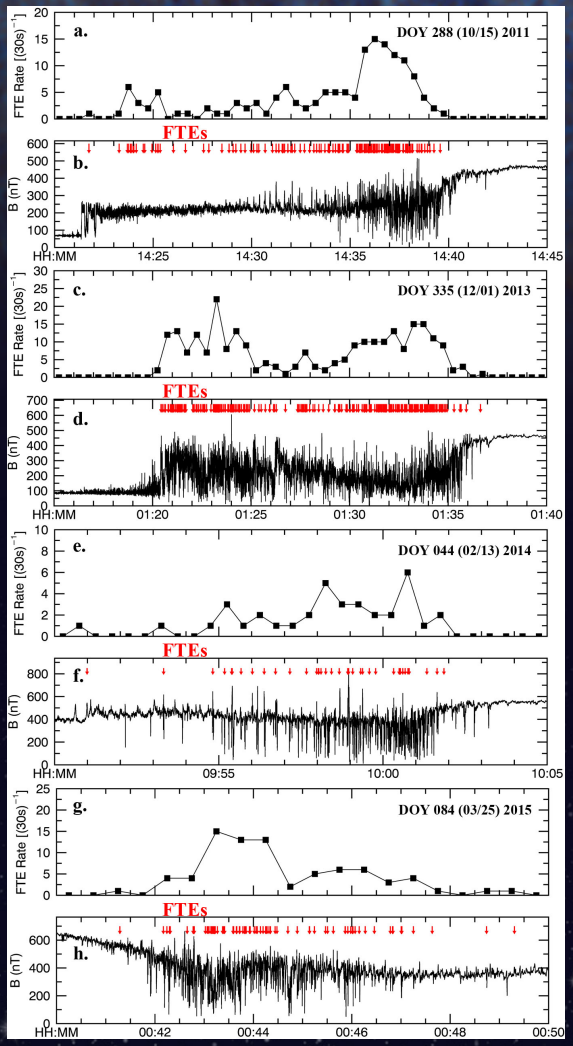
See also:
Hood & Schubert (1979)
Slavin et al. (2014)
Heyner et al. (2016)
Jun et al. (2016)
Johnson et al. (2016)



(Jia, Slavin et al., submitted, 2018)

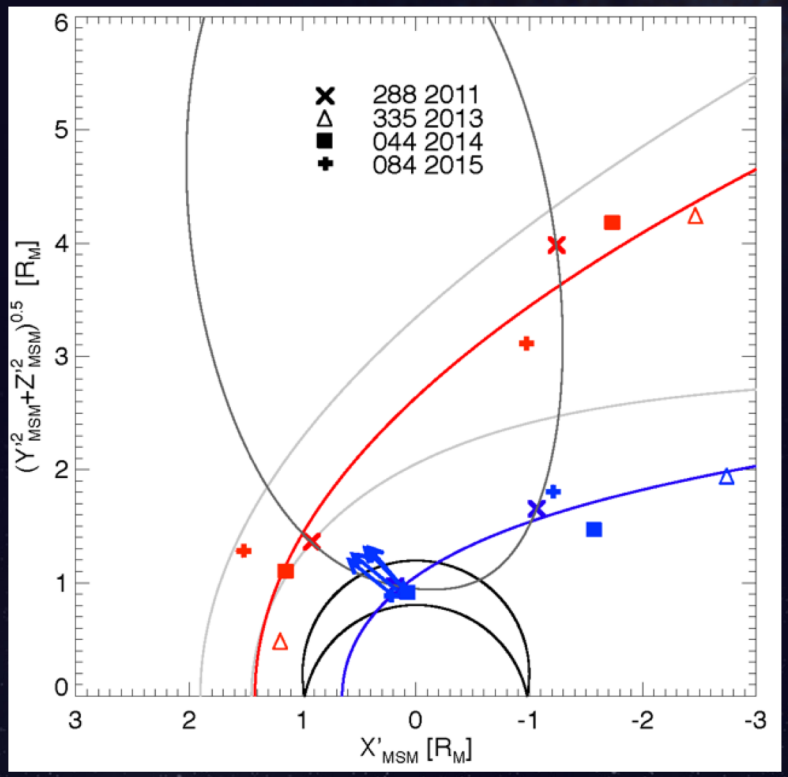
Disappearing Dayside Magnetosphere (DDM) Events

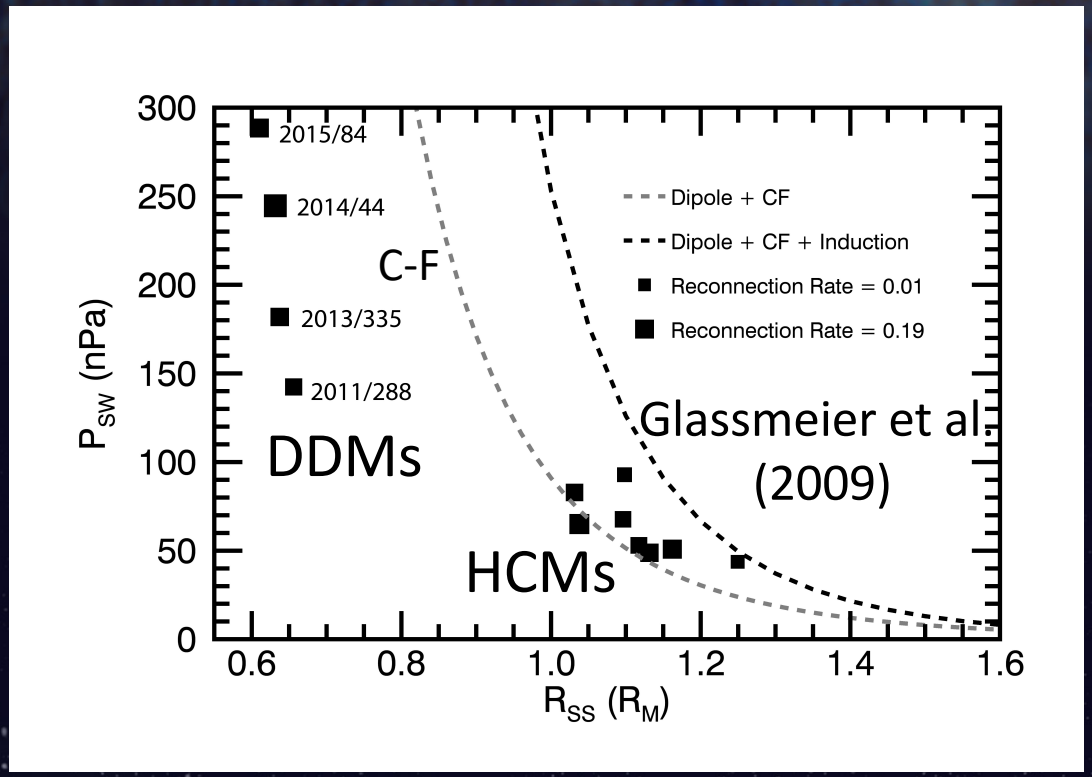




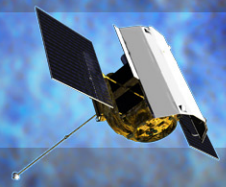
Slavin et al. (*in prep.*, 2018)

DDM Event: Boundary Locations

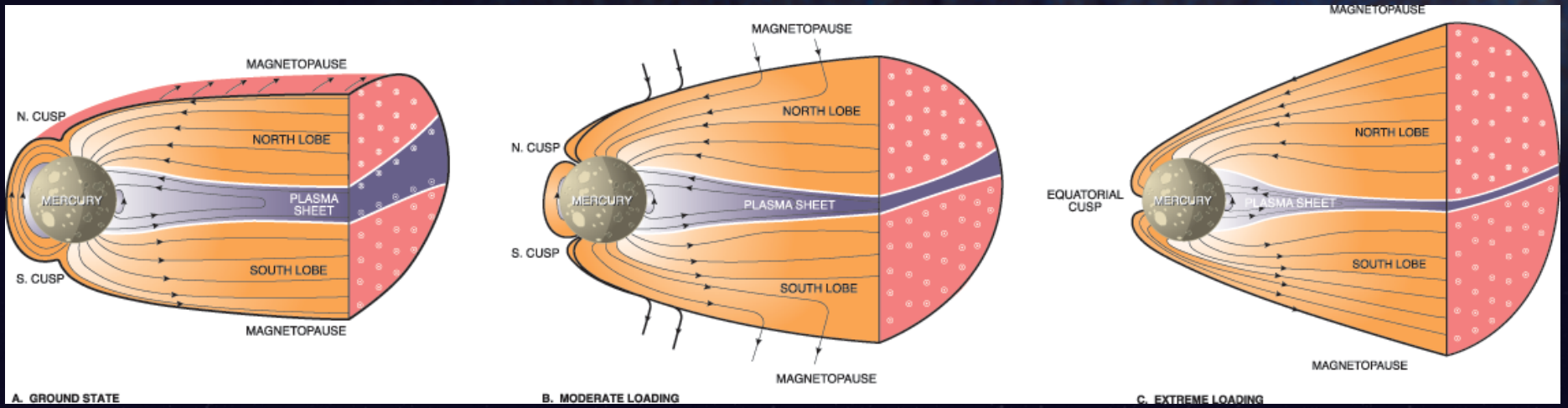




Slavin et al. (*in prep.*, 2018)

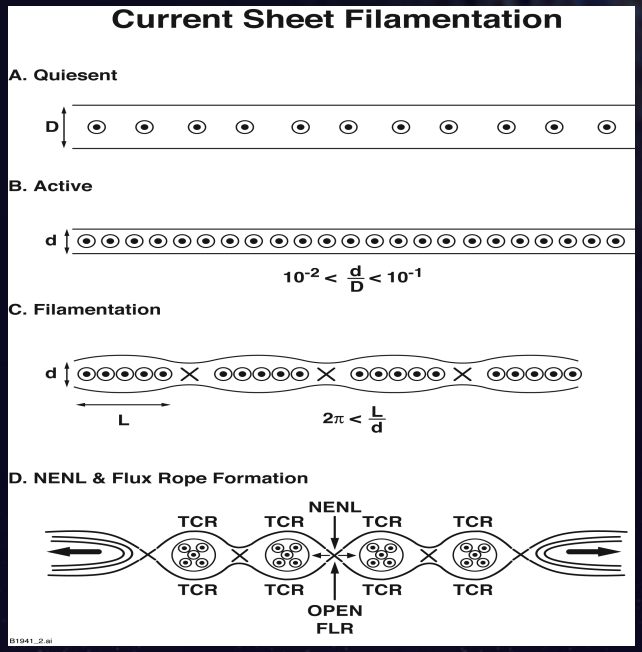


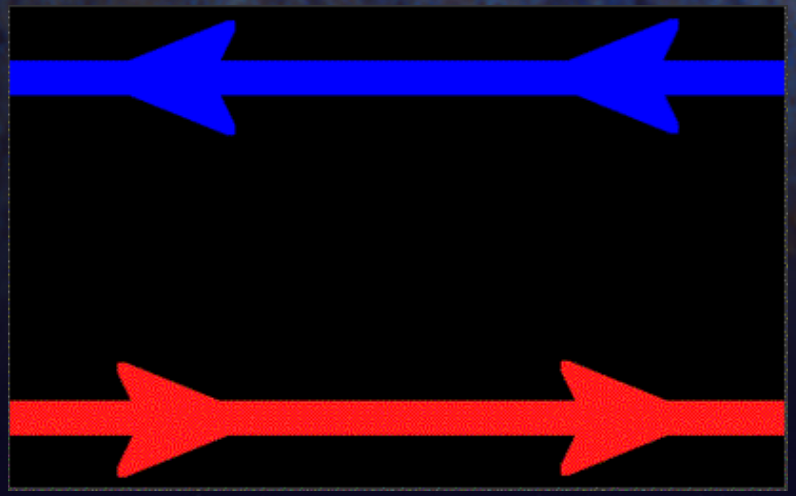
9. Earth-like Magnetospheric Substorms?

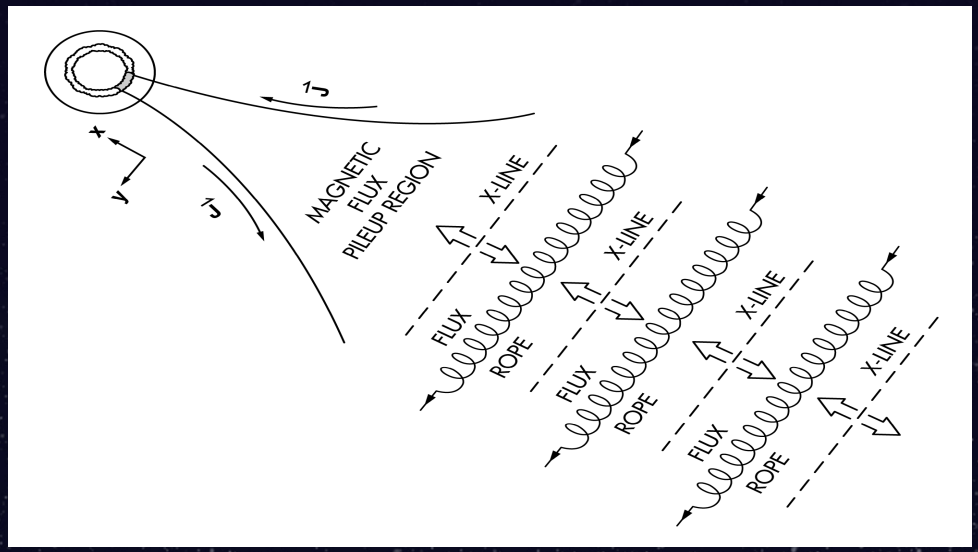


Slavin et al. (2009)

How does Reconnection work in Planetary Magnetotails?



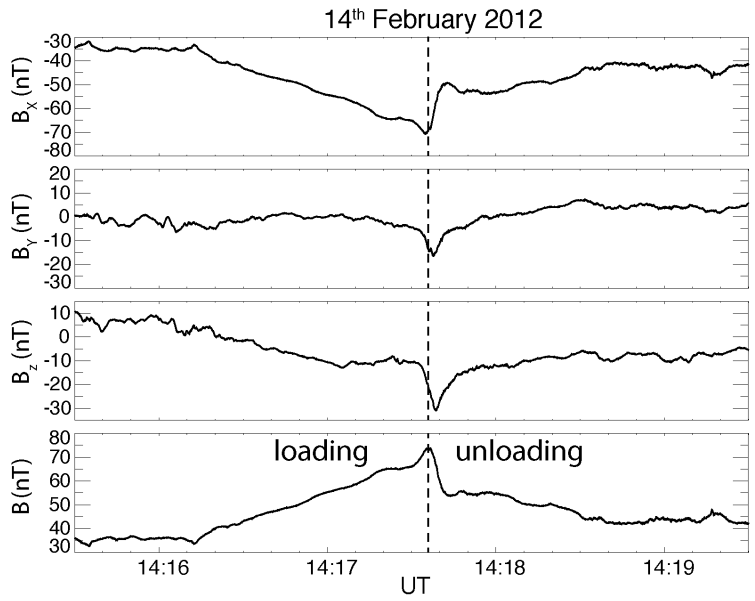


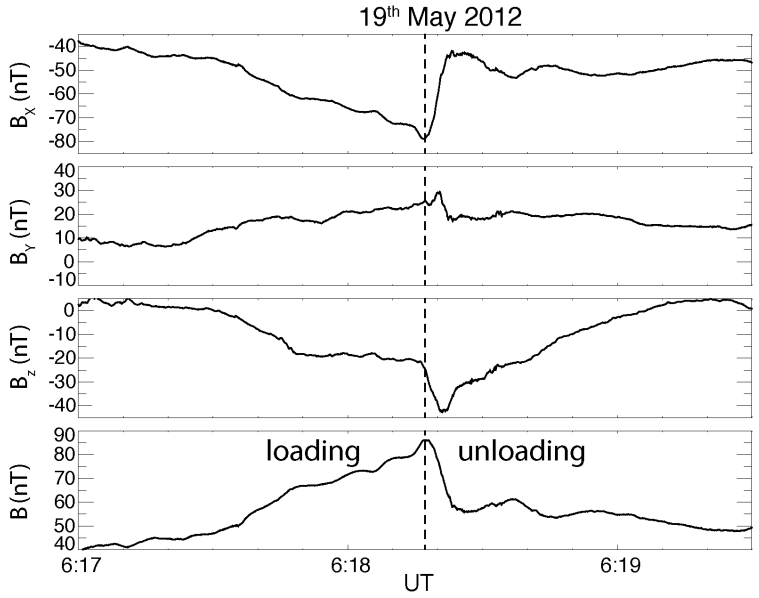


ESA

Slavin et al. (2003)

Extreme Loading – Unloading Events





Slavin et al. (*Mercury*, 2018)

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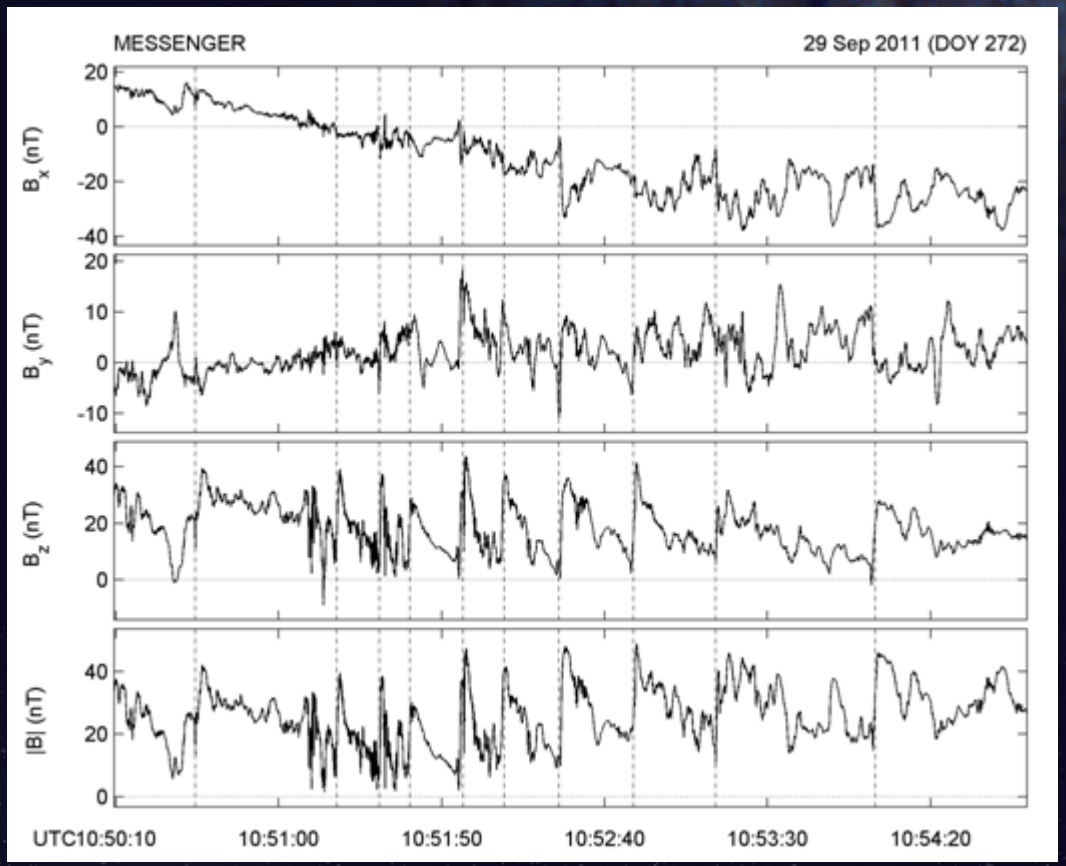
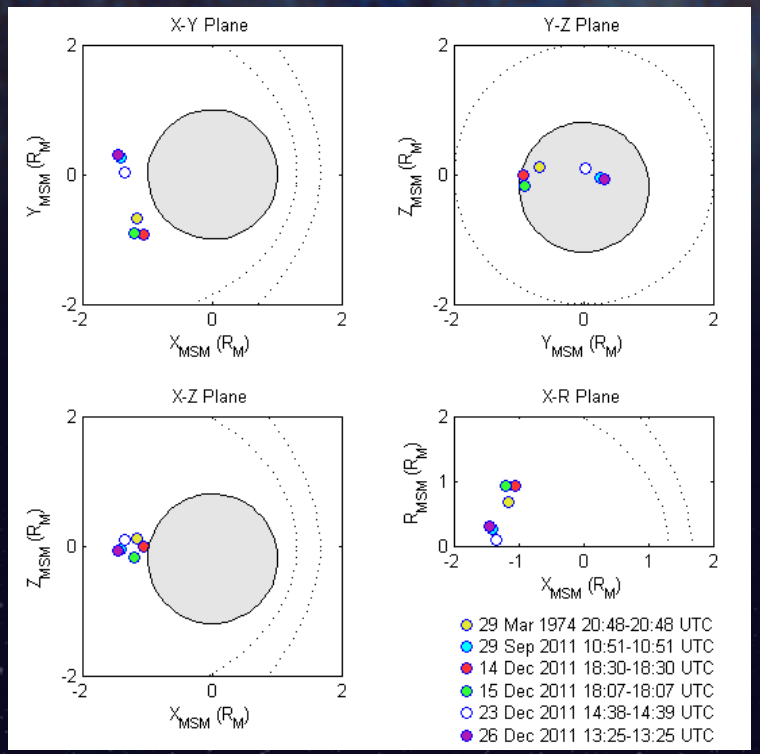
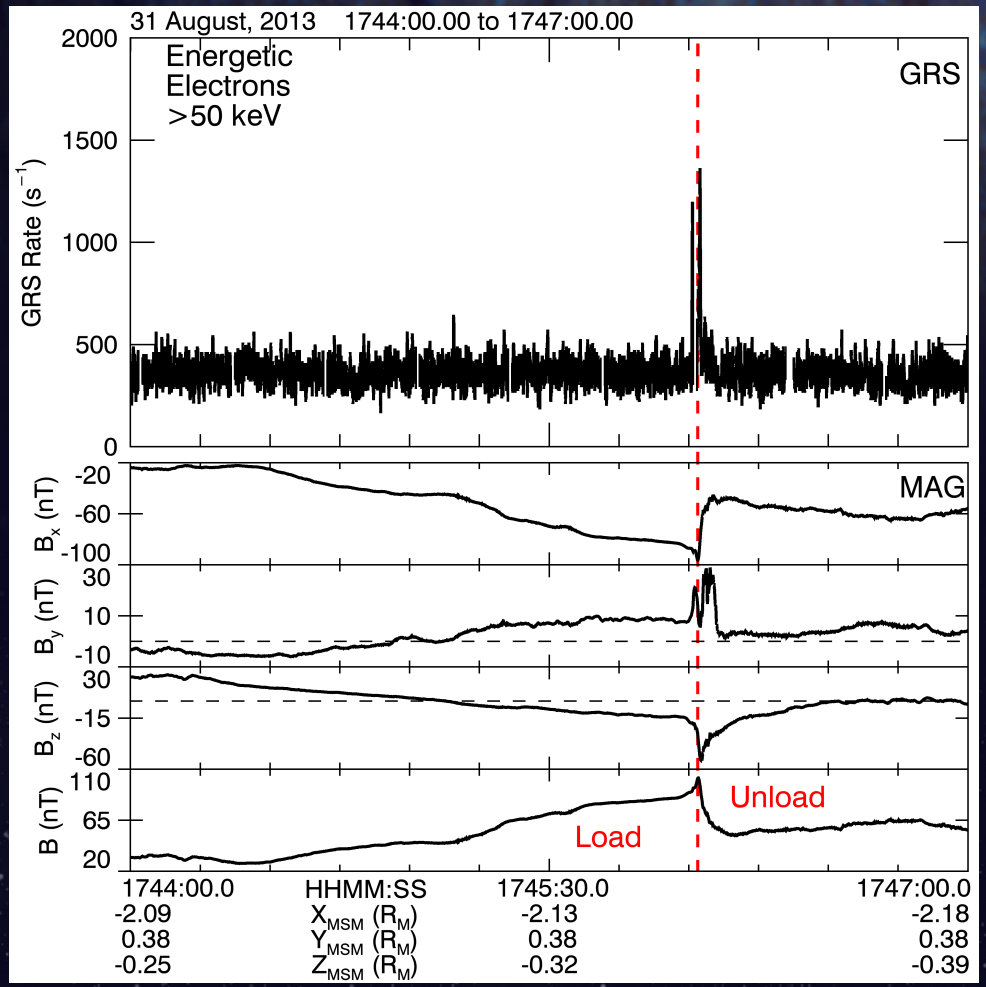
Near-tail Dipolarization Fronts





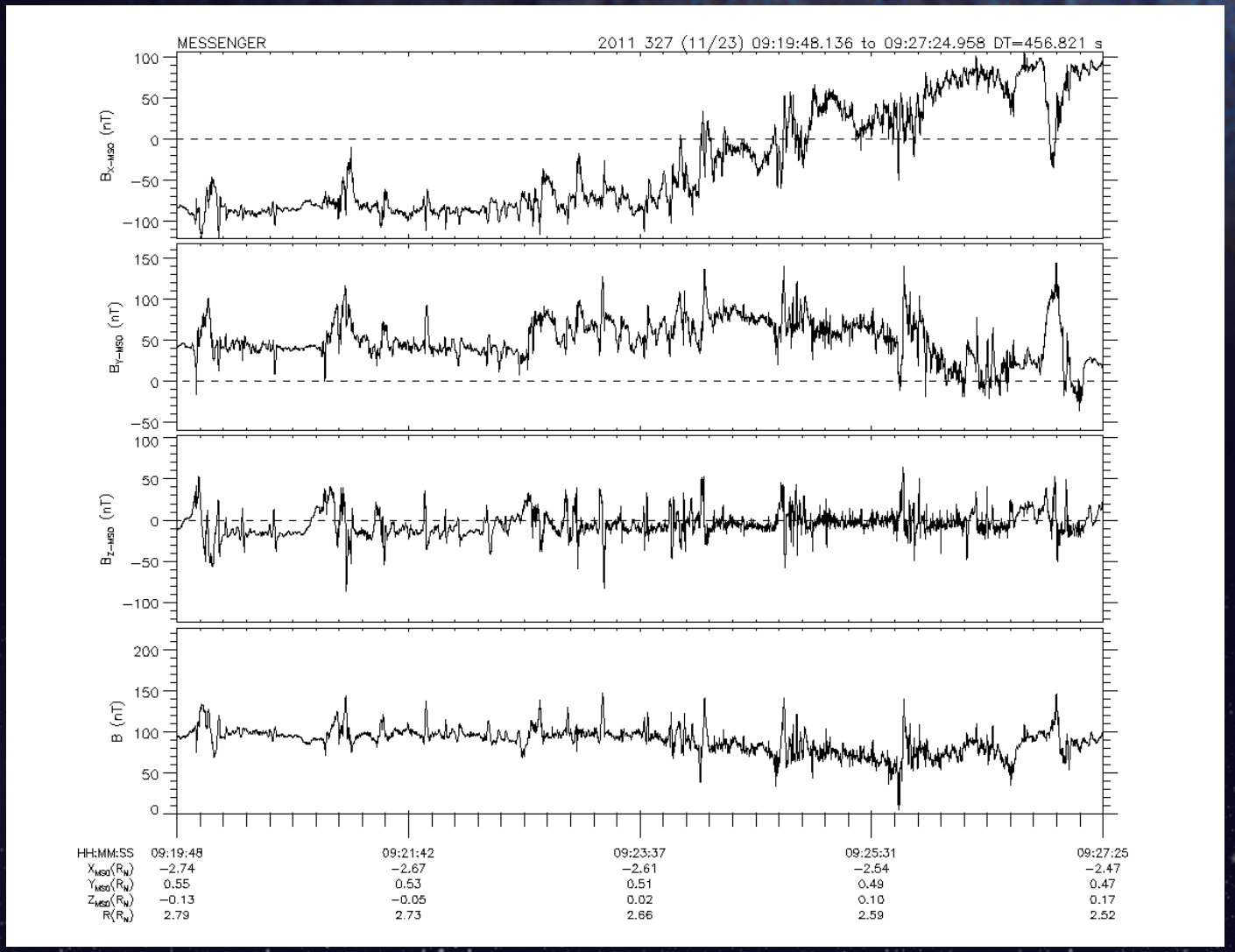
Sundberg et al. (2012)

Tail Loading/Unloading & Energetic Electrons



Courtesy R. M. Dewey

Flux Ropes are Common in the Cross-tail Current sheet!



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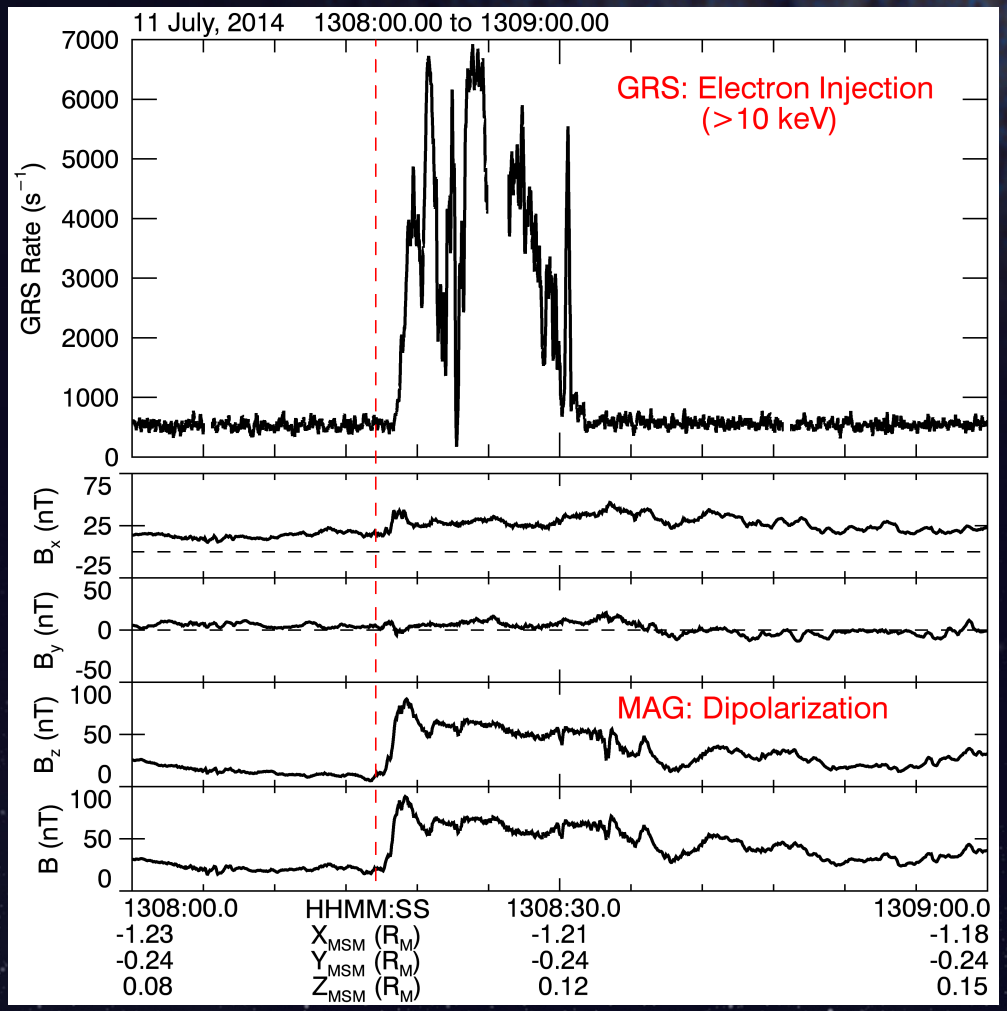
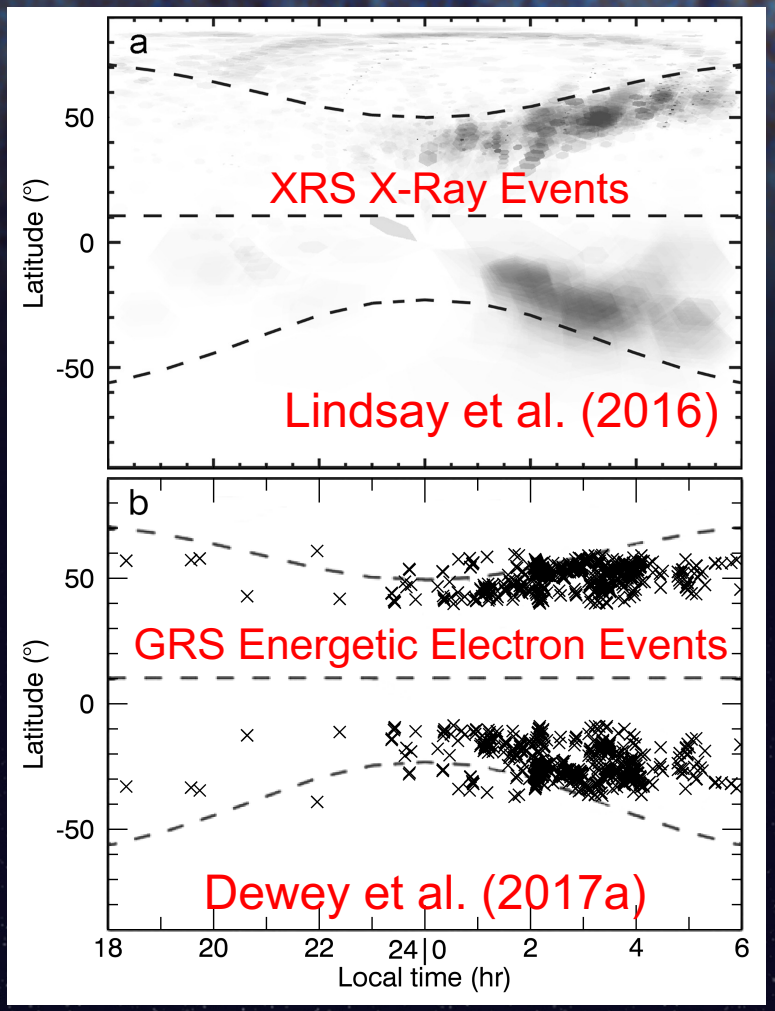
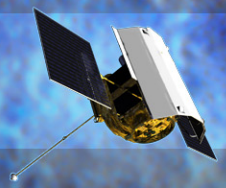
10. Nightside Energetic Electron Precipitatin & X-Ray Auroras





Dewey et al. (2017)

See also: Baker et al. (2016). Sun et al. (2017)
Poh et al. (2017) and Rong et al (2017)



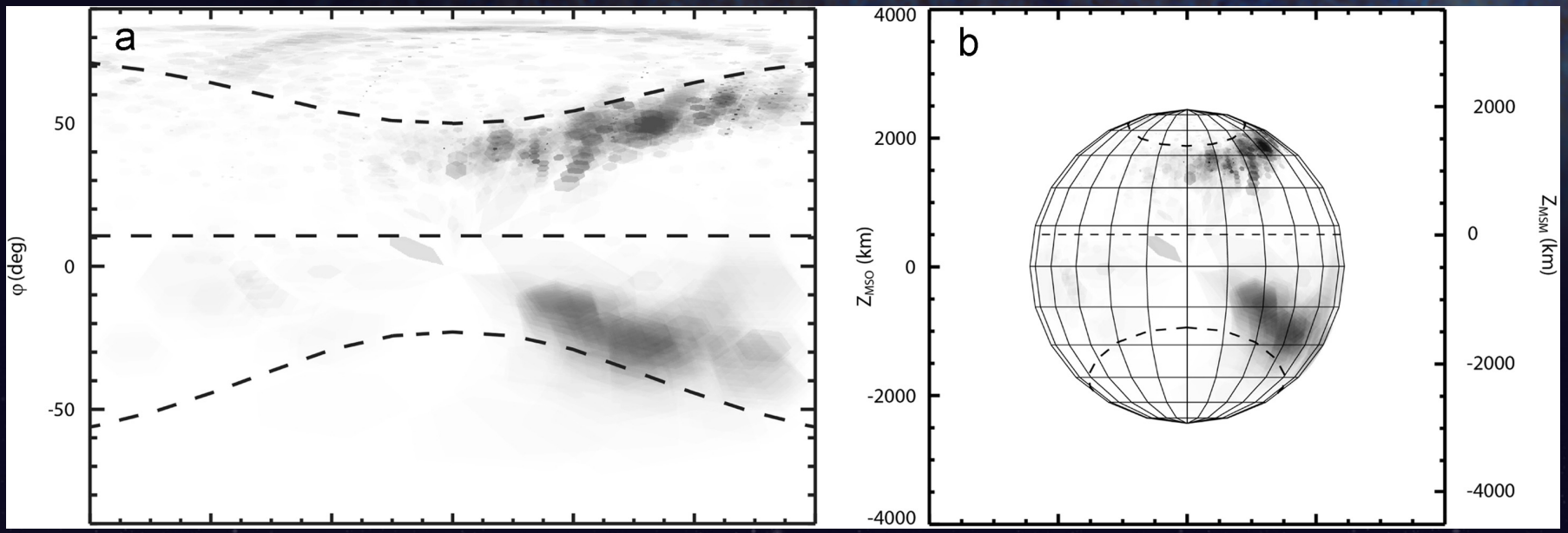
Summary

- Proximity to the Sun matters! Mercury's magnetosheath is low beta and supports the the thickest plasma depletion layer in the Solar System!

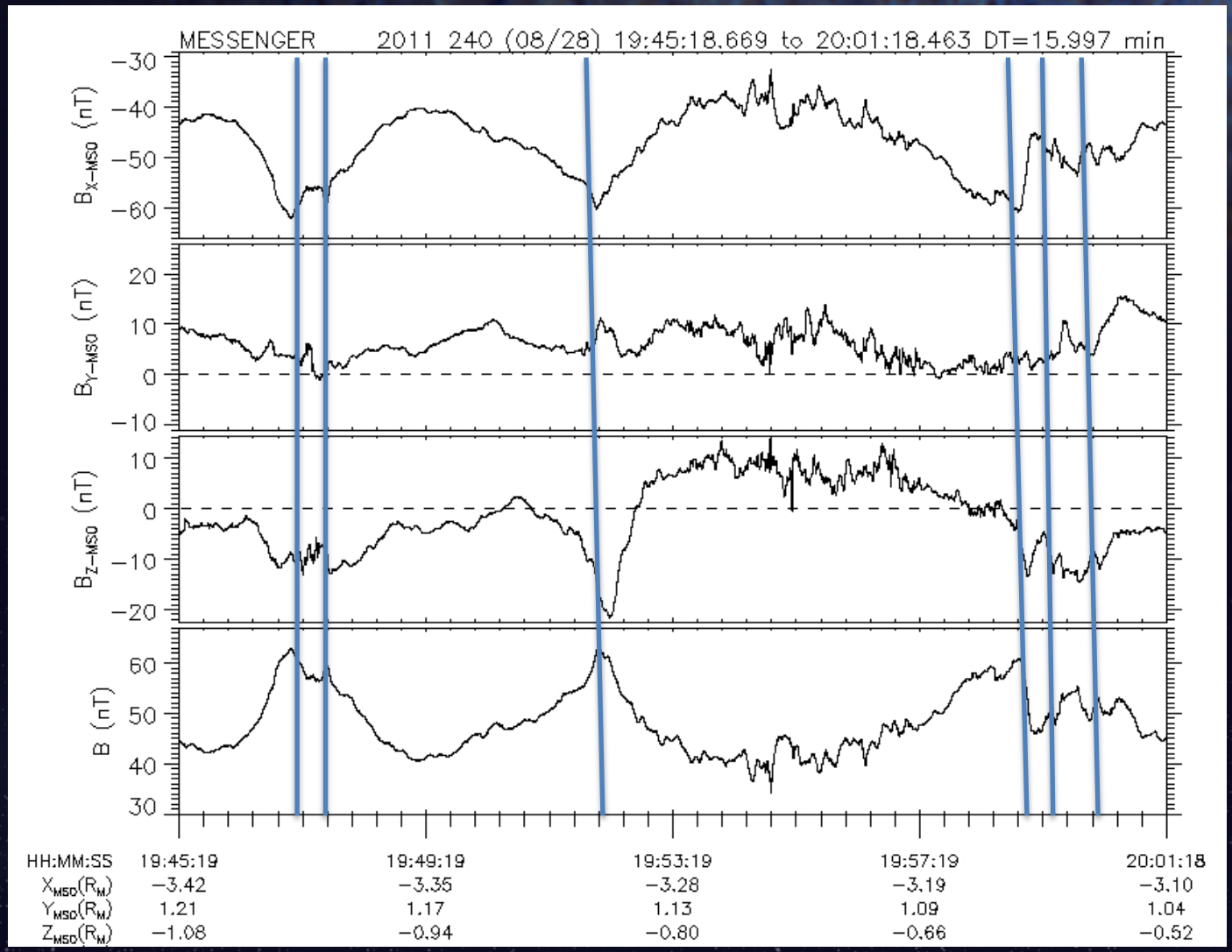
- Reconnection rate at Mercury's magnetopause appears to be 3 to 10 times faster than at Earth and it depends upon IMF intensity and magnetosheath plasma beta as much or more than southward IMF Bz (i.e. magnetic shear across the magnetopause).

- Mercury's magnetotail exhibits Dungey-type loading - unloading cycles on time-scales of only a few min, but their amplitudes can reach 100% as compared with ~ 10% at Earth.

- Approximately once per Earth year MESSENGER observed "Disappearing Dayside Magnetosphere Events" during extremely high dynamics pressure and southward IMF conditions caused by CMEs that expose the forward hemisphere of Mercury's surface to direct solar wind impact.


a
50
0
-50
φ (deg)
b
4000
2000
0
-2000
-4000
Z_{MSO} (km)
2000
0
-2000
-4000
Z_{MSM} (km)

Load – Unloading Events at Mercury



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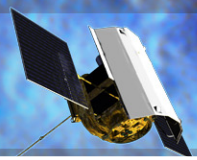
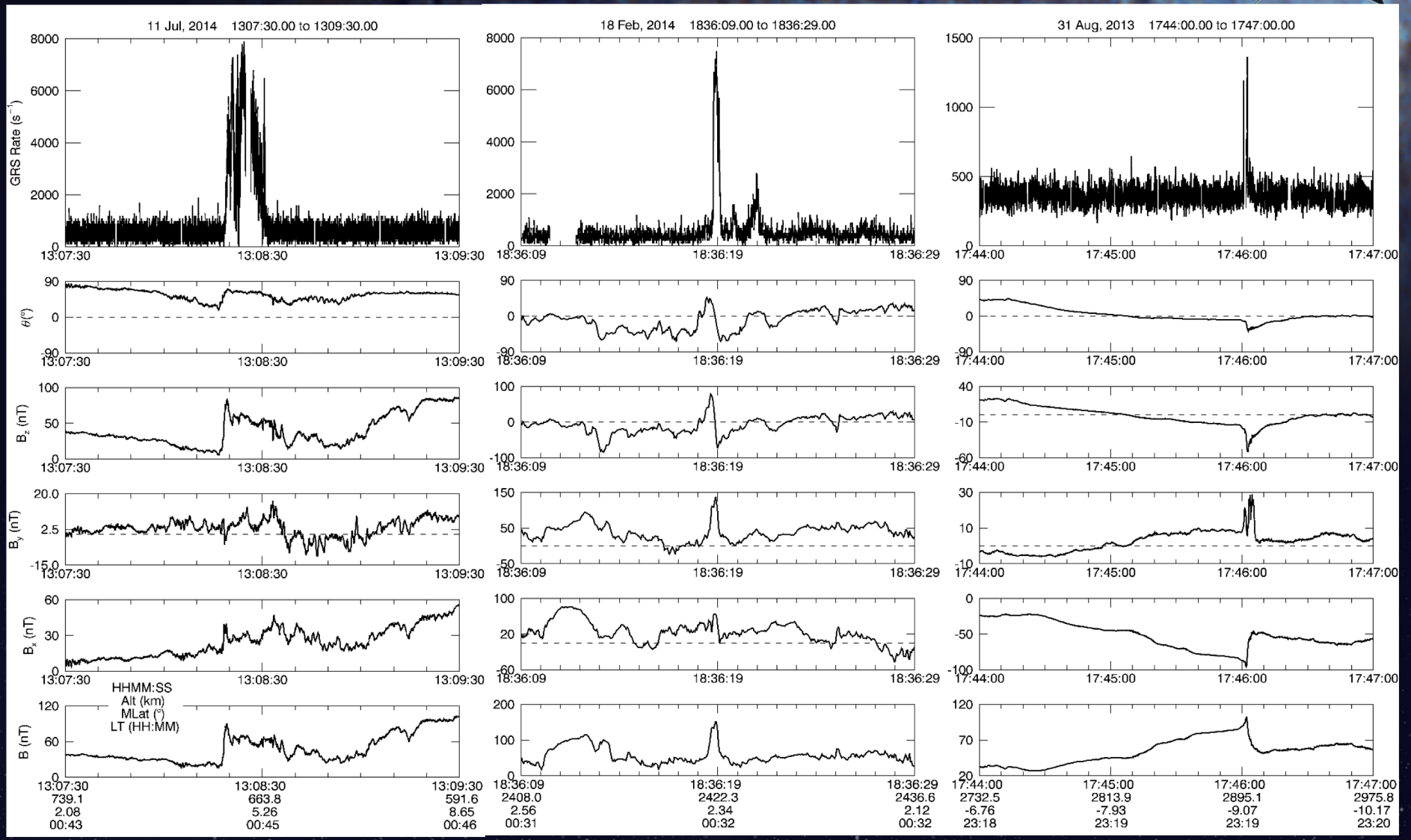
APL





Betatron acceleration

Fermi acceleration?

X-Line Separatrix Layer

Dewey et al. (2016)

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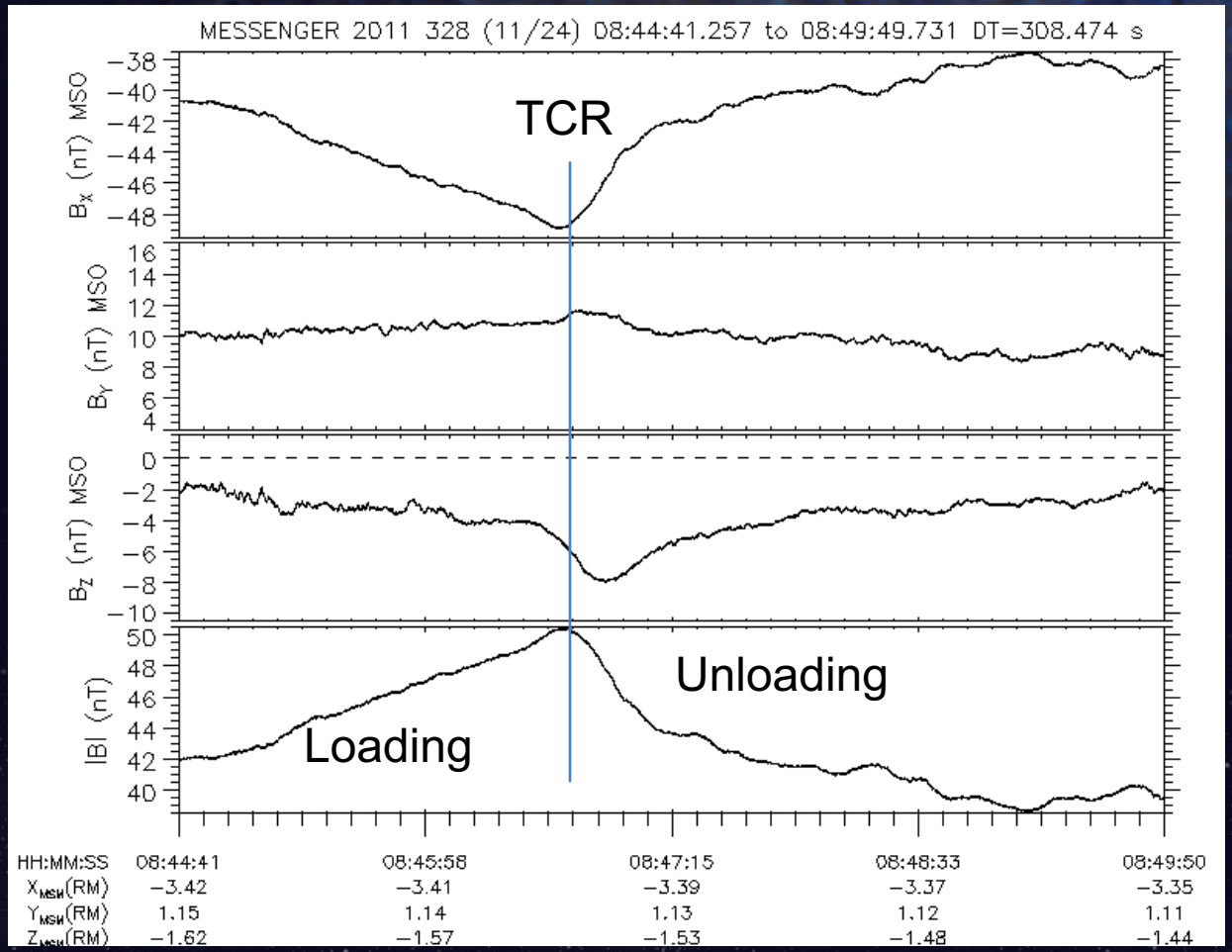
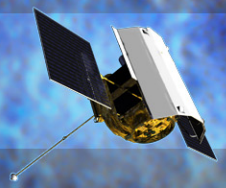
~ 2 - 3 min Substorm at Mercury





10. Summary

- Proximity to the Sun matters: Mercury's magnetosphere is the most dynamic in the Solar System!
- Mercury's large iron core enhances the shielding effect of its intrinsic magnetic field and supports strong inductive coupling between to the magnetosphere and planet.
- Mercury's core also supports steady-state field-aligned currents and a downward flux of electromagnetic energy from the magnetosphere and solar wind.
- Charged particle precipitation and sputtering result in significant mass exchange between the magnetosphere, exosphere and Mercury's surface.
- Although different from Earth in many ways, only Mercury appears to support terrestrial-type magnetospheric substorms.